Here, E_{side} is the scalar field along the side of a triangle, J_{nside} is the electron current along the side and J_{pside} is the hole current along the side. This model is the most non-physical but has the advantages of better robustness and calculation speed and is compatible with older device simulators.

The most complex and physically sound model is selected by specifying E.DIR on the IMPACT statement (see Equation 3-363).

$$G = \alpha_n\left(\left|\frac{E_{tri}\cdot J_{ntri}}{J_{ntri}}\right|\right)J_{ntri} + \alpha_p\left(\left|\frac{E_{tri}\cdot J_{ptri}}{J_{ptri}}\right|\right)J_{ptri} \quad 3\text{-}363$$

In this model, the ionization coefficients are a function of the field in the direction of the current. If the dot product of E and J is negative, then the field component is taken as 0. Consequently, impact ionization may only occur when a current is dominated by the drift term. This model is the most physically sound and is the default model for the field dependence of the impact ionization coefficients.

Another option is to abandon the use of the Electric field and adopt the gradient of the Quasi-Fermi levels to use when calculating the ionization coefficients.

$$G = \alpha_n(\left|\underline{\nabla}\phi_n\right|)J_n + \alpha_p(\left|\underline{\nabla}\phi_p\right|)J_p \quad 3\text{-}364$$

The modulus of the quasi-Fermi level gradients across each triangle are used, which is similar to the E.VECTOR electric field model. Using the gradient of quasi-Fermi level has the advantage that built-in electric fields (such as those existing across highly doped *n-p* junctions) do not result in an artificially high ionization rate at low contact biases. In the situation where the current is dominated by drift rather than diffusion, the gradient of quasi-fermi level will be essentially equal to the electric field. The impact ionization coefficients calculated from gradient of quasi-fermi level are in that case the same as the E.DIR or E.VECTOR options. To enable this model, specify GRADQFL on the IMPACT statement.

Local Electric Field Models for Impact Ionization

Selberherr's Impact Ionization Model

The ionization rate model proposed by Selberherr [245] is a variation of the classical Chynoweth model [53]. Activate this model by using the SELB parameter of the IMPACT statement, which is based upon the following expressions [280]:

$$\alpha_n = \mathrm{AN}\,exp\left[-\left(\frac{\mathrm{BN}}{E}\right)^{\mathrm{BETAN}}\right] \quad 3\text{-}365$$

$$\alpha_p = \mathrm{AP}\,exp\left[-\left(\frac{\mathrm{BP}}{E}\right)^{\mathrm{BETAP}}\right] \quad 3\text{-}366$$

Here, E is the electric field in the direction of current flow at a particular position in the structure and the parameters AN, AP, BN, BP, BETAN, and BETAP are defined on the IMPACT statement and have the default values shown in Table 3-81. In the case of AN, AP, BN, and BP you can define a value of electric field, EGRAN V/cm, where for electric fields, >EGRAN V/cm, the parameters are: AN1, AP1, BN1, BP1, while for electric fields, <EGRAN V/cm, the parameters become AN2, AP2, BN2, and BP2.

The AN and BN parameters are also a function of the lattice temperature in this model [171]. The temperature dependence of these coefficients is defined as follows:

$$\mathtt{AN} = AN_{1,2}\left(1 + \mathtt{A.NT}\left[\left(\frac{T_L}{300}\right)^{\mathtt{M.ANT}} - 1\right]\right) \quad \text{3-367}$$

$$\mathtt{AP} = AP_{1,2}\left(1 + \mathtt{A.PT}\left[\left(\frac{T_L}{300}\right)^{\mathtt{M.APT}} - 1\right]\right) \quad \text{3-368}$$

$$\mathtt{BN} = BN_{1,2}\left(1 + \mathtt{B.NT}\left[\left(\frac{T_L}{300}\right)^{\mathtt{M.BNT}} - 1\right]\right) \quad \text{3-369}$$

$$\mathtt{BP} = BP_{1,2}\left(1 + \mathtt{B.PT}\left[\left(\frac{T_L}{300}\right)^{\mathtt{M.BPT}} - 1\right]\right) \quad \text{3-370}$$

The parameters associated with these equations are shown in Table 3-82.

An alternative model for temperature dependence of AN and AP is given by the following expressions:

$$\mathtt{AN} = AN_{1,2} + \mathtt{CN2} \cdot \mathtt{T} + \mathtt{DN2} \cdot \mathtt{T}^2 \quad \text{3-371}$$

$$\mathtt{AP} = AP_{1,2} + \mathtt{CP2} \cdot \mathtt{T} + \mathtt{DP2} \cdot \mathtt{T}^2 \quad \text{3-372}$$

where T is temperature and CN2, CP2, DN2, and DP2 are user-specifiable parameters on the IMPACT statement. By default, the temperature model of Equations 3-367 and 3-368 are used and the values of CN2, CP2, DN2 and DP2 are all zero. You can use the temperature dependence models described in Equations 3-371 or 3-372 or both by specifying non-zero values for CN2, CP2, DN2 and DP2.

The critical fields given by BN and BP may be modeled based on band gap and optical phonon mean free paths using the following expressions:

$$\mathtt{BN} = \frac{E_g}{q\lambda_n^0} \quad \text{3-373}$$

$$\mathtt{BP} = \frac{E_g}{q\lambda_p^0} \quad \text{3-374}$$

where $q\lambda_n^0$ and $q\lambda_p^0$ are the optical phonon mean free paths for electrons and holes and E_g is the local temperature dependent band gap. The free paths are modeled using the following expressions:

$$\lambda_n^o = \mathtt{LAMDAH}\frac{tanh[q\mathtt{OPPHE}/2kT_L]}{tanh[q\mathtt{OPPHE}/2k300]} \quad \text{3-375}$$

$$\lambda_n^o = \text{LAMDAE}\frac{tanh[q\text{OPPHE}/2kT_L]}{tanh[q\text{OPPHE}/2k300]} \quad 3\text{-}376$$

where T is the lattice temperature and LAMDAE, LAMDAH, OPPHE are user-specifiable parameters listed in Table 3-83. To enable the models described by Equations 3-369, 3-370, 3-371, and 3-372, either specify $BN_{1,2}$ or $BP_{1,2}$ or both as zero.

Table 3-81 User-Definable Parameters in the Selberherr Impact Ionization Model

Statement	Parameter	Default
IMPACT	AN1	7.03×10^5 cm^{-1}
IMPACT	AN2	7.03×10^5 cm^{-1}
IMPACT	AP1	6.71×10^5 cm^{-1}
IMPACT	AP2	1.58×10^6 cm^{-1}
IMPACT	BN1	1.231×10^6V/cm
IMPACT	BN2	1.231×10^6 V/cm
IMPACT	BP1	1.693×10^6 V/cm
IMPACT	BP2	2.036×10^6 V/cm
IMPACT	BETAN	1.0
IMPACT	BETAP	1.0
IMPACT	EGRAN	4×10^5 V/cm

Table 3-82 Temperature Coefficient Parameters of the Selberherr Impact Ionization Model for Silicon in Equations 3-367 to 3-370

Statement	Parameter	Default
IMPACT	A.NT	0.588
IMPACT	B.NT	0.248
IMPACT	A.PT	0.588
IMPACT	B.PT	0.248
IMPACT	M.ANT	1.0
IMPACT	M.BNT	1.0
IMPACT	M.APT	1.0
IMPACT	M.BPT	1.0

Table 3-83 User specifiable parameters for the optical phonon mean free path model in Equations 3-375 and 3-376.			
Statement	**Parameter**	**Default**	**Units**
IMPACT	LAMDAE	6.2×10^{-7}	cm
IMPACT	LAMDAH	3.8×10^{-7}	cm
IMPACT	OPPHE	0.063	eV

Selberherr Tabular Model

Given a tabulation of ionization rate versus field or reciprocal field, as it more commonly appears, you can extract values of the A and B coefficients in Equations 3-364 and 3-365 assuming a value for BETA (in this case 1.0) for each consectutive pair of samples.

ATLAS provides an interface to automate this process whereby you will provide a table of ionization rates versus fields or reciprocal fields and the Selberherr parameters are automatically derived and used to reproduce a representation of continuous ionization rates versus field to be used in the Selberherr model.

To use this feature, you must assign the values of IINOFF or IIPOFF or both to the name of a file containing an ASCII table of the ionization rates as a function of field for electrons or holes or both.

The table itself must first contain the integer number of samples (pairs) in the table. This is followed by that number of pairs of either field - ionization rate or reciprocal field - ionization rate values.

If reciprocal field is used, the designator flag "oe" must preceed the samples. If the "oe" designator flag is missing the ordinate values will be interpreted as field values.

The units of fields are V/cm. Ionization rates units are 1/cm. Reciprocal field units are cm/V.

Comments may be embedded in the file following a "#" character in the first column any row in the file.

The following is an example ionization file:

```
# Oguzman, I., Bellotti, E. and Brennan, K., "Theory of hole
initiated impact

# ionization in bulk zincblende and wurtzite GaN", J. Appl. Phys,
B. 81,

# 15 June 1997, pp. 7827-7834.

oe

5

2.465e-07 4.711e+04

2.840e-07 1.350e+04

3.335e-07 3.670e+03

4.011e-07 3.658e+02

5.012e-07 1.098e+01
```